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# TECHNICAL MEMORANDUM

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" LIQUEFACTION RESEARCH PROGRAM, by

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## INTRODUCTION

A recent analysis conducted at NAS North Island by the Civil Engineering Laboratory (1) determined that a major earthquake-induced soil liquefaction threat to the Naval Air Station exists. However, it became apparent during the study that the precision with which liquefaction investigations can be carried out, particularly with regard to ocean front facilities, leaves much to be desired. Thus, better liquefaction hazard evaluation techniques, for application to the marine depositional environment that exists at many Naval establishments, must be developed.

The objective of the work effort outlined herein was to define goals and items for research to be pursued in a major research program dealing with the earthquake-induced liquefaction hazard at Naval shore facilities.

The major shortcomings in available liquefaction evaluation technology appear to be related to the lack of validated or, in some cases, even credible procedures. It is apparent that realistic large-scale tests for investigating the liquefaction phenomenon are desirable, and this study initially was directed toward potential techniques for conducting large-scale field tests. These tests were to use sequential explosions, or very large oscillators, etc. Although such approaches should not be ruled out for the future, it became apparent that, because of the great number of complex variables which control liquefaction potential, the results to be derived from an individual large-scale test might not warrant the very large expenditures to be incurred by the Navy at this time. This study, therefore, was redirected towards examining the overall field of liquefaction prediction and evaluation, and concentrated upon a broad program to investigate the feasibility of adapting available and anticipated liquefaction analysis developments to Navy requirements.

This study, in addition to permitting CEL to remain current in developments within the field of liquefaction prediction, also permitted some consideration to be given to specific deficient areas. An analytical procedure was developed (2) for analyzing liquefaction occurring beneath loaded foundations rather than in the free field, which is treated in conventional analysis. Also, the probability of liquefaction occurrence combined with the probability of a specific level of seismic ground motion has been considered (3). Some attention has also been directed towards compiling a compendium of experimental laboratory liquefaction data (4) from other agencies to be used as an indication of both the range of liquefaction behavior, and of the diversity of the results that can be obtained using conventional testing capabilities.

Pertinent items for further research are presented herein, as well as a general outline for a research program thought to best meet the needs of the Navy.

## ITEMS FOR FURTHER RESEARCH

The major requirements for a satisfactory liquefaction analysis procedure can be summarized in terms of three basic requirements:

- a. The ability to predict the characteristics (magnitudes, durations, etc.) and recurrence intervals of possible seismic ground motions.
- b. A reliable procedure for defining site conditions with respect to liquefaction potential.
- c. An analysis method capable of predicting the response or damage levels to be experienced by a specific facility, at a particular site, when subjected to prescribed magnitudes of ground motion.

The first requirement above lies primarily within the fields of the seismologist and geophysicist and will not be considered further herein. The proposed research program will deal primarily with the second and third requirements, i.e., identifying the danger at a particular site and defining the degree of damage to be incurred.

The initial phases of this research program must evaluate the results to be obtained from directing the best available state-of-the-art technology to Navy application, keeping in mind the overall goal of ending up with a reliable, proficient approach to liquefaction analysis. In order to facilitate this, it is necessary that the most sophisticated current techniques be applied to Navy-unique situations. This would include such things as conducting cyclic triaxial tests on undisturbed samples of the sensitive silts prevalent in the coastal shoreline depositional environment (such as the filled, former bight areas at NAS North Island). It would also include carrying out computer analyses of waterfront-type structures using the most recent complex computer codes, such as NONSAP, and ascertaining the validity of such analyses. The proposed research effort will be limited primarily to suggesting modifications or additions to general liquefaction evaluation technology, and does not encompass such things as theoretical computer code development or broad general studies.

A list of items which could contribute markedly toward a satisfactory Navy capability for treatment of liquefaction hazard is presented in Table I.

## DISCUSSION

The items for further research presented in Table I are selected to meet the requirements of either more efficient site evaluations or more reliable damage prediction techniques. Item 1 of Table I will permit evaluation of the liquefaction potential of materials that are unique to the Navy coastal environment, using the most advanced available soil testing procedures. Although these testing procedures are still somewhat open to contention, they can at least better define the relative risk potential



as compared with the risk potential estimated from the more extensively tested, idealized soil types (such as Monterey No. 0 sand) that are not typical of Navy sites. In addition, by selecting specimens from NAS North Island, where both standard penetration tests and static cone penetration tests have already been conducted, a correlation between complex laboratory tests and simple field tests will be established for those problem materials. Item 2 would extend such correlations to other types of soil material. It must be kept in mind, however, that tying in simplified field tests with laboratory procedures is not the final answer to this problem, since the validity of the laboratory tests in representing field response is still somewhat open to question.

Item 3 deals with a new field investigational tool which intuitively offers some promise. Should the results obtained by using such a device be encouraging, correlating the results with the North Island soil profile data would provide an additional, very valuable correlation between soil parameters and at least hypothetical liquefaction potential.

Item 4 is quite general, but it primarily deals with the pressing requirement for improved field or site evaluation techniques. This is related somewhat to Item 5 which is aimed at a better definition of site liquefaction potential.

Item 6 could increase the confidence factor in current liquefaction evaluation technology (and the situation at North Island) and suggest alternative directions to be pursued for Navy application.

Item 7 is directed towards achieving more reliable damage predictive methods. Currently, evaluations of the response of shore facility structures are analyzed by computer codes which may or may not reliably model the true structural behavior. In some cases, the computer solutions may not even be applicable. A first step in the search for valid analytical techniques must be an unbiased look at what is presently available.

The evaluation of analytical techniques may be enhanced by Item 8, using data that are presently available. Model tests (as referred to in Item 9) could also be used in this regard. Scale models of waterfront facilities might be tested by contract to facilities having this equipment.

The use of a sand tank might provide an expedient approach to singling out particular aspects of the liquefaction phenomenon. Although a typical sand tank could not simulate liquefaction due to cyclic loading, liquefaction could perhaps be produced hydraulically and used to study the influence of such things as soil stratification, gradation, sloping land, and concentrated loads, both at the surface and supported by foundation piles. Such studies could also be useful in validating computer programs such as APOLLO and GADFLY.

Larger scale experiments might be conducted in the field using large oscillators, or sequential explosions, etc. Such endeavors could be justified if they could be used to validate analytical codes that appear otherwise satisfactory.

The most valuable research data that could be obtained would be measurements made on prototype Navy structures, such as covered by Items 10 and 11. Obviously, such studies would be very expensive and extend over long periods. Nevertheless, such investigations might be pursued in conjunction with other authorities, such as the U.S. Geological Survey or the Army Corps of Engineers. Ideally, one would obtain reliable response data measurements on well-defined prototype structures under design level ground motions. Items of particular interest would be regions of liquefaction occurring in soils confined by cofferdams or tied bulkheads, beneath drydocks or cyclopean walls, or in the vicinity of pile-supported structures.

#### RECOMMENDATIONS

The overall project schedule presented in Figure 1 is recommended. It may be observed that the degree of explicitness of the individual tasks decreases as that task gets further "down the road" chronologically. Thus, an initial task is to obtain undisturbed specimens from problem areas at NAS North Island, whereas the study of innovative site evaluation techniques to be commenced during the latter part of FY79 may include everything from field measurements to soil sampling techniques. This situation is considered desirable as it will permit flexibility in later stages, should changes be warranted based upon new information.

This outline is laid out so as to provide tangible benefits at the end of each fiscal year. Thus, should the project be terminated prior to the five-year planning period, the expended efforts would not be wasted. In some cases, it is necessary for some of the tasks to overlap more than one fiscal year, but even in those cases, the tasks are generally such that partial benefits can be derived.

#### REFERENCES

1. Civil Engineering Laboratory, Technical Report R-847 "An Earthquake Analysis of the Liquefaction Potential at the Naval Air Station, North Island," by J. Forrest and J. Ferritto, Port Hueneme, CA, Sep 1976.
2. Forrest, J.B. and Ferritto, J.M., "A Generalized Treatment of the Initial Static Shear During Seismic Liquefaction." Paper accepted for publication in the Central American Conference on Earthquake Engineering, El Salvador, C.A., Jan 9-14, 1978.
3. Ferritto, J.M. and Forrest, J.B., "Siting Structures in Seismic Liquefaction Areas." Paper presented at the 9th International Conference on Soil Mechanics and Foundation Engineering, Tokyo, Japan, July 1977.

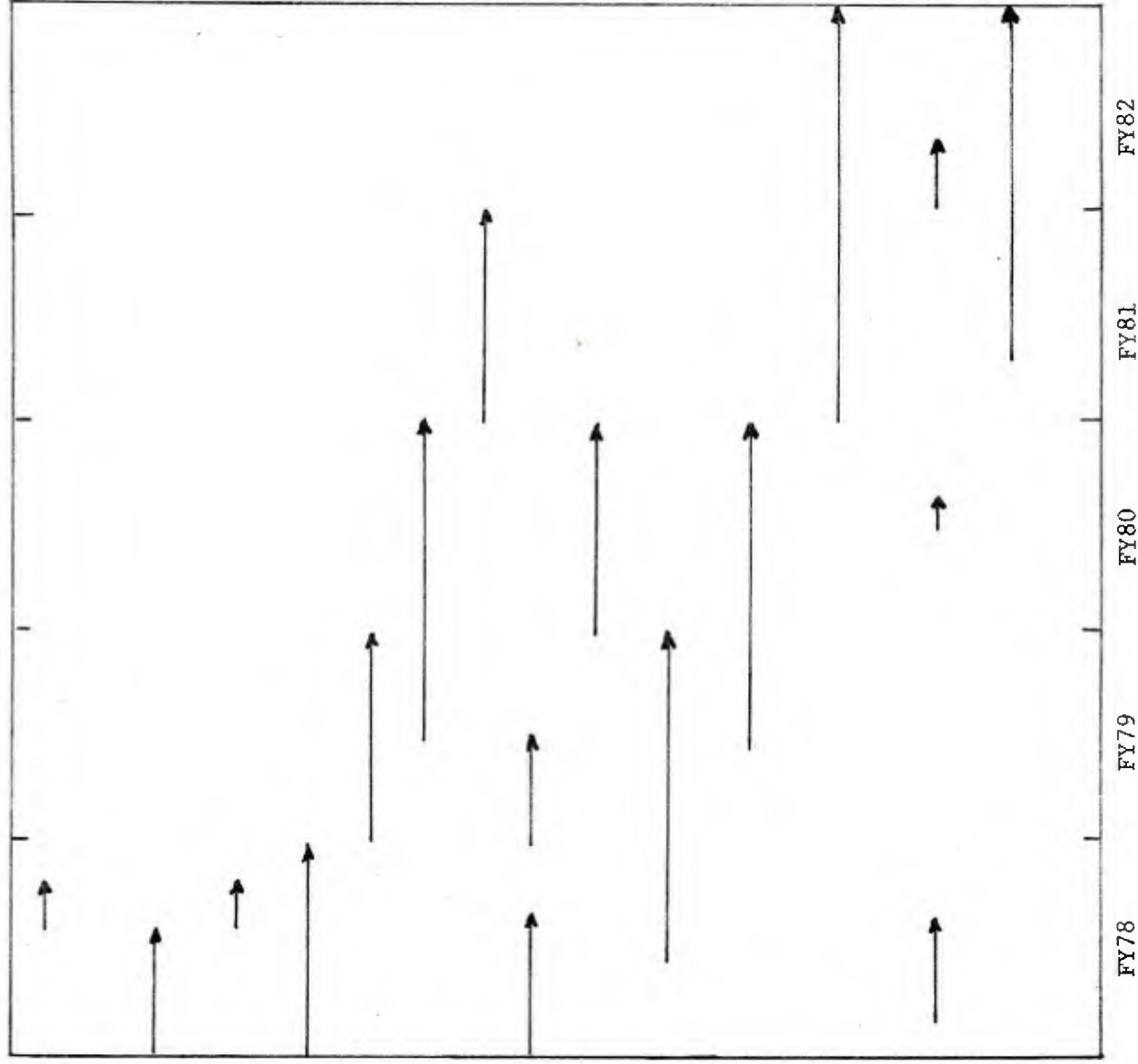
4. Civil Engineering Laboratory: "A Compilation and Analysis of Cyclic Triaxial Test Data." Progress report to FHWA (Order No. 5-3-0208) on project "Highway Bridge Response to Seismically Induced Soil Liquefaction" June 1977.

TABLE I

1. Obtain undisturbed samples of the highly micaceous sands and the extremely sensitive silts encountered at NAS North Island, and perform cyclic triaxial tests.
2. Develop a compendium of comparisons between simplified field tests and index properties, and cyclic laboratory tests using data from other agencies such as the Nuclear Regulatory Commission.
3. Investigate developments involving the use of a piezometer, embedded in a standard friction cone. If warranted, use this device at sites such as North Island.
4. Investigate other field reconnaissance techniques, such as measuring shear wave velocities, developing some procedure for measuring insitu "A" parameter values, or use of dissolvable resins for obtaining undisturbed samples.
5. Develop some form of hazard potential weighting system based upon such factors as depositional history, index tests, site characteristics, etc.
6. Compare recent liquefaction prediction techniques developed in Japan and China with U.S. practice.
7. Evaluate the use of NONSAP, GADFLY and other recent computer codes for providing reasonable analysis for Navy problems.
8. Gather and correlate available response data on Navy and Navy-type facilities, such as the Trident program, drydock and cofferdam monitoring programs by other authorities, etc.
9. Conduct model tests of Navy-type facilities using:
  - a. Shake tables
  - b. Sand tanks
  - c. Large field oscillators or vibrators.
10. Instrument Naval structures in active seismic areas to monitor acceleration levels and pore water generation characteristics.
11. Conduct prototype tests on Naval structures by means of large vibrators or sequential explosions.



Figure 1. PROGRAM LAYOUT



1. Compare recent Asian liquefaction practices.
2. Evaluate sampling techniques and obtain undisturbed samples at NAS North Island.
3. Run cyclic tests (compare with field and index tests).
4. Evaluate and apply cone piezometer.
5. Conduct sand tank experiments.
6. Conduct shake table experiments.
7. Conduct field model tests.
8. Investigate computer code capabilities.
9. Study feasibility of code developments.
10. Develop compendium of soil data correlations.
11. Study innovative site evaluation techniques.
12. Quantify influence of various soil/site factors.
13. Evaluate available facility response studies.
14. Instrument prototype structures.

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